Congressional Testimony, 2005

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Before the Committee on Science
U.S. House of Representatives

January 26, 2005

Mr. Chairman and Members of the Committee, thank you for this opportunity to discuss the recent tragedy in South Asia and what can be done to reduce the threat that tsunamis and earthquakes pose to coastal communities in the United States and around the globe. Events such as this serve as a tragic reminder of our vulnerability to natural hazards. While the United States is not as vulnerable to tsunamis as other regions of the world, we do face significant risk.

On December 29, the President asked the Departments of Interior and Commerce to determine whether our systems are adequately prepared for a tsunami on our coasts. As a result, the Administration announced its commitment to implement an improved domestic tsunami detection and warning system. As part of the President's plan, the U.S. Geological Survey (USGS) will strengthen its ability to detect global earthquakes both through improvements in the Global Seismographic Network (GSN), which we support jointly with the National Science Foundation (NSF), and through around-the-clock analysis of earthquake events. The changes that are proposed for USGS clearly have a dual purpose, improving our capacity to respond to earthquakes as well as supporting the tsunami warning program of the National Oceanic and Atmospheric Administration (NOAA).

In addition to earthquake monitoring and reporting, the USGS conducts a number of activities aimed at improving tsunami hazard assessments, education, and warnings, including geologic investigations into the history of and potential for tsunami occurrence, coastal and marine mapping, and modeling tsunami generation. Although most tsunamis are caused by earthquakes, they can also be caused by volcanic eruptions, submarine landslides, and onshore landslides that cause large volumes of rock to fall into the water. All of these tsunami-generating hazards can impact the United States. Consequently, a broad range of USGS work in earthquake, volcano and landslide hazards, and coastal and marine geology, contribute to better understanding of tsunami impacts and occurrences.

Additionally, USGS is playing a role in relief efforts for nations impacted by the December 26 disaster by providing relief organizations worldwide with pre- and post-tsunami satellite images and image-derived products that incorporate information on population density, elevation, and other relevant topics. These images and products are being used by relief organizations to determine where relief efforts are most critical and how best to carry out those relief operations. In our efforts to assist and improve relief efforts, we work closely with partners at NOAA, the U.S. Agency for International Development, other federal agencies, and in academia. For example, USGS scientists are part of international teams conducting post-tsunami investigations in Sri Lanka and Indonesia with the goal of applying the knowledge developed to other vulnerable areas in the United States and around the globe.

USGS is also working with NOAA and other domestic and global partners through the Global Earth Observing System of Systems (GEOSS) and other mechanisms. Through GEOSS, improved monitoring capabilities must be firmly linked into all-hazards warning systems and, the most important link in the chain, public education and mitigation programs. As we move forward, we must bear in mind that this was an earthquake disaster as well as a tsunami disaster, and we must learn from both. This is not just a scientific endeavor; it is a matter of public safety.

Earthquake and Tsunami of December 26, 2004

This was the second year in a row in which a deadly earthquake occurred near the end of the year. In 2003, a magnitude 6.6 quake struck Iran's ancient city of Bam, killing over 30,000 people. In 2004, the deadly quake was a magnitude 9 earthquake that initiated 20 miles below the seafloor off the western coast of Sumatra, the fourth largest earthquake to strike the planet since 1900 and the largest since a magnitude 9.2 earthquake struck Alaska in 1964. The earthquake and resulting tsunami killed more than 150,000 people around the Indian Ocean, two-thirds of them in northern Sumatra, whose inhabitants experienced not only the severe shaking from the earthquake but also the tsunami's full force.

As with other giant earthquakes, this one took place along a subduction zone, where one of the tectonic plates that make up the

Earth's rigid outer layer is being thrust beneath another (see Figure 1). The Sunda trench is the seafloor expression of such a plate boundary where the Indian plate is thrusting under the overriding Burma plate. The size of an earthquake is directly related to the area of the fault that is ruptured. This rupture propagated northward along the plate boundary fault for over 750 miles beneath the Nicobar and Andaman Islands almost to Burma with a width of over 100 miles and slip along the fault averaging several tens of feet.

It is difficult to comprehend the scope of a magnitude 9 earthquake. When we hear the term earthquake magnitude, we think of the Richter scale, which was the first of several scales developed to measure the earthquake size from the seismic waves they generate. These scales are logarithmic such that each whole number represents an order of magnitude larger in the seismic waves generated. So a magnitude 7 earthquake is 10 times larger than a magnitude 6 and 100 times larger than a magnitude 5. However, the amount of energy released goes up much faster. This magnitude 9 earthquake released 32 times more energy than a magnitude 8 earthquake and 1000 times more energy than a magnitude 7 earthquake such as the one that struck the San Francisco Bay area in 1989. The energy released by the Sumatra earthquake is roughly equal to that released by all the earthquakes, of every size, everywhere in the world since the mid-1990s. It's important to remember that our own coasts, Alaska in 1964 and the Pacific Northwest in 1700, were the site of earthquakes as large as the Sumatra earthquake.

A great deal of that energy was transferred to the Indian Ocean's waters and ultimately to its surrounding shores. Along the length of the fault rupture, the seafloor was jolted upward by as much as 15 feet, lifting trillions of gallons of sea water a volume more than 30 times that of the Great Salt Lake - and generating the tsunami that swept both east, inundating the coast of Sumatra, Thailand and Burma, and west, crossing the open ocean at hundreds of miles per hour on its way to the coasts of India, Sri Lanka, and eventually eastern Africa.

Tsunamis strike the Indian Ocean less frequently than the Pacific Ocean, which is ringed by subduction zones, but there have been at least a half dozen Indian Ocean tsunamis caused by earthquakes in the past 200 years. What had been the deadliest tsunami in the region was not caused by an earthquake but by the explosion of Krakatau volcano in 1883. The tsunami generated by the collapse of that volcano killed 36,000 people on Java, Sumatra and neighboring islands.

It is important to emphasize that not all large subsea earthquakes generate tsunamis. For example, four days before the Sumatra earthquake, a magnitude 8.1 earthquake struck the seafloor south of New Zealand near the Macquarie Islands. Instead of generating a thrusting motion as in a subduction zone, this earthquake occurred on a strike-slip fault, moving side to side like the San Andreas Fault, a motion much less efficient at creating a tsunami. No tsunami was generated. Even earthquakes generated in subduction zones may not produce tsunami, depending on whether the fault rupture reaches the seafloor, the amount of displacement on the fault and other factors. One of the key roles of a tsunami detection system is to avoid false warnings that cause costly and unnecessary evacuations that can undermine people's willingness to heed warnings in the future. In addition to buoys and tide gauges, seismic data may be able to provide an additional check, and research in this area could improve our ability to recognize tsunami-causing events in minutes.

U.S. earthquake monitoring networks and their role in tsunami warning center operations

To monitor earthquakes in the United States, the USGS has begun to install and operate the Advanced National Seismic System (ANSS), which was established by the National Earthquake Hazard Reduction Program (NEHRP) in 2000 (P.L. 106-503). The system includes a 63-station ANSS Backbone Network, which is capable of locating most felt earthquakes nationwide and provides data in near-real-time to USGS. Extending our capability in high-hazard areas of the country are 17 regional seismic networks that provide detailed coverage and rapid response, local expertise in event analysis and interpretation, and data. Our ANSS partnerships--which include universities, state government agencies and NSF--greatly leverage USGS seismic monitoring capabilities. The key products of the system are rapid and accurate earthquake locations and magnitudes, delivered directly to users for emergency response.

In several of the highest-risk urban areas in the United States, dense arrays of seismic sensors designed to record strong ground motion have been deployed under ANSS. These areas include the Los Angeles, San Francisco, Seattle, Anchorage and Salt Lake City metropolitan regions. When triggered by an earthquake, data from these sensors are automatically processed into detailed maps of ground shaking

("ShakeMaps"), which in turn feed loss estimation and emergency response. Also, because earthquake losses are closely tied to the vulnerability of buildings and other structures, USGS monitors earthquake shaking in structures in support of engineering research, performance-based design, and rapid post-earthquake damage evaluations. If placed in certain critical facilities, these sensors can contribute to critical post-earthquake response decisions.

USGS has set a minimum performance goal of determining automated locations and seismic magnitudes within 4 minutes or less in the U.S. This is exceeded in many ANSS regions; for example, the magnitude 6.5 San Simeon, California, earthquake of December, 2003, was automatically located within 30 seconds. Earthquake data, including locations, magnitudes, other characterizations and, where requested, the actual seismograms, are automatically transmitted from USGS and regional centers to federal response departments and agencies such as the NOAA tsunami warning centers, the Department of Homeland Security, including the Federal Emergency Management Agency (FEMA), State governments, local emergency managers, utility operators, several private sector entities, and the public and media. USGS does not currently have 24 x 7 earthquake analysis, but analysts are on-call in the event of a large earthquake worldwide. The Administration has recently proposed 24 x 7 operations as a key needed improvement in response to the Indian Ocean tsunami disaster.

To monitor seismic events worldwide, the Global Seismographic Network (GSN) maintains a constellation of 128 globally distributed, modern seismic sensors. USGS operates about two-thirds of this network, and the University of California, San Diego, operates the other third with NSF support. NSF also funds the IRIS (Incorporated Research Institutions for Seismology) Consortium to handle data management and long-term archiving. Two GSN stations were the first to detect the December 26, 2004, Sumatra earthquake, and automated analysis of these data generated the "alerts" of strong recorded amplitudes sent to NOAA and USGS. At the present time, about 80% of GSN stations transmit real-time data that can be used for rapid earthquake analysis and tsunami warning. The Administration is requesting funding to extend the GSN's real-time data communications, as well as to improve station uptime through more frequent maintenance. These changes will result in improved tsunami warning in the United States and globally.

Through the National Tsunami Hazard Mitigation Program, the USGS, NOAA, FEMA, and five western States (Alaska, California, Hawaii, Oregon and Washington) have worked to enhance the quality and quantity of seismic data provided to the NOAA tsunami warning centers and how this data is used at the State and local level. This program has funded USGS to upgrade seismic equipment for regional seismic networks in northern California, Oregon, Washington, Alaska and Hawaii. The seismic data recorded by the USGS nationally and globally are relayed to the NOAA tsunami warning centers. USGS and NOAA also exchange earthquake locations and magnitude estimates, with USGS providing the final authoritative magnitudes of events. USGS is also working with emergency managers in the Pacific Northwest to support public warning systems in coastal communities there.

Improving earthquake monitoring in the United States--with consequent improvements to public safety and the reduction of earthquake losses--can be achieved through the modernization and expansion of the ANSS, including expansion of seismic sensor networks nationwide, the upgrading of the associated data processing and analysis facilities, and the development of new earthquake products. Funding over the past three years has focused on installation of over 500 new seismic sensors in high-risk urban areas. The FY05 appropriation for ANSS is $5.12 million. The President's proposed increase in funding to USGS in response to the tsunami disaster would allow USGS to make critically needed improvements to performance in one key element of ANSS, providing 24 x 7 operations capacity and completing software and hardware upgrades to speed processing times. These improvements will enhance USGS support of NOAA's tsunami warning responsibility.

The threat from tsunamis and great earthquakes in the Pacific

The concentration of U.S. tsunami warning efforts in the Pacific reflects the greater frequency of destructive tsunami in that ocean. Approximately 85% of the world's tsunamis occur in the Pacific. This is due to many subduction zones ringing the Pacific basin--the source of submarine earthquakes of large enough magnitude (greater than ~7) to produce tsunami. While Hawaii's position in the middle of the Pacific makes it uniquely vulnerable to ocean-wide tsunami, this chain of volcanic islands also faces a hazard from locally generated tsunami due to local earthquakes or submarine landslides. In 1975, a magnitude 7.2 earthquake just offshore the island of Hawaii caused a tsunami that killed 2 with maximum runup height (elevation reached by tsunami as they move inland from the shoreline) of 47 feet.

U.S. Insular Areas in the Pacific also face a threat both from ocean-wide tsunami as well as ones generated locally. The volcano Anatahan in the Northern Marianas, which began actively erupting on January 5, 2005, serves as a reminder that inhabitants and U.S. military interests in the Commonwealth of the Northern Mariana Islands and the Territory of Guam are threatened by nine islands with active volcanoes that have the potential to generate hazardous ash plumes as well as tsunamis through eruption-induced collapse. The risks from tsunamis to the inhabited islands are poorly understood, and tsunami inundation modeling is needed to assess the threat represented by such an event.

Our knowledge of what may be the greatest risk to the United States does not come from our tsunami experiences of the last half century, but rather to the detective work of USGS and other scientists in the Pacific Northwest. In contrast to the San Andreas Fault, where the Pacific and North American plates are sliding past one another, a subduction zone known as Cascadia lies offshore further north, its size nearly identical to that of the rupture zone of the Sumatra earthquake (see Figure 2). On January 26, 1700, the Cascadia subduction zone broke in a great earthquake, probably from northernmost California to the middle of Vancouver Island. Along the Pacific coast in Oregon, Washington, California, and British Columbia, this huge event of the same general size of the Sumatra earthquake, caused coastal marshes to suddenly drop down several feet. This change in land elevation was recorded by the vegetation living in and around the coastal marshes. For example, along the Copalis River in Washington State, Western Red Cedar trees that have lifespans of over 1000 years were suddenly submerged in salt water. Over the next few months, those trees died. By comparing tree rings of the still standing dead trees with nearby trees that were not submerged, paleoseismologists established that the trees were killed during the winter of 1699-1700.

Digging through river bank deposits along the Copalis and other rivers in Cascadia, paleoseismologists found a pervasive, black sand sheet left by the tsunami. Because the sands deposited by the tsunami are transported by the tsunami waves, paleoseismologists can combine the location of tsunami sands with the change in marsh elevation to get an approximate idea of the length of the rupture for the 1700 earthquake. Tsunami sands have been found from Vancouver Island to Humboldt Bay in California.

Once paleoseismologists found evidence of the 1700 event, they combed written records in Japan to see if evidence existed of an unknown tsunami wave. Several villages recorded damage in Japan on January 27, 1700, from a wave that people living along the coast could not associate with strong ground shaking. The coast of Japan had been hit, not unlike Sri Lanka and Somalia, by a distant tsunami, but this tsunami came from the west coast of North America. By modeling the travel time across the Pacific, paleoseismologists were able to establish the exact date of the last Cascadia subduction zone event.

Based on estimates of the return interval, USGS scientists and others have estimated that there is a 10-14 percent chance of a repeat of the Cascadia magnitude 9 earthquake and tsunami event in the next 50 years. Since that initial discovery in the early 1980s, many of the elements of the seismic systems for the Pacific Northwest described above have been put in place along with improved building codes to address the higher expected ground shaking and increased public education through the efforts of state and local emergency managers.

The December 26, 2004, earthquake and tsunami together cause us to focus on the similar threat from the Cascadia subduction zone that faces the Pacific Northwest as well as our long Alaskan coastline. Here I cannot emphasize enough the critical role played by our partners in State and local government, especially the state emergency managers. Largely through the efforts of the National Tsunami Hazard Mitigation Program partnership, much has been accomplished. Seismic systems have been improved, allowing NOAA's West Coast and Alaska Tsunami Warning Center to issue warnings within minutes of a significant offshore earthquake. Inundation maps, graphic representations of estimates of how far inland future tsunami waves are likely to reach, are available for most major communities in northern California, Oregon, and Washington. Working with FEMA, public education has been stressed, and emergency managers have begun installing all-hazard warning systems. USGS is co-funding a $540,000 pilot project in Seaside, Oregon with FEMA and NOAA to develop risk identification products that will help communities understand their actual level of risk from tsunami in a way that could be conveyed on existing flood maps. The goal of the project is to develop techniques that can be used to determine the probability and magnitude of tsunami in other communities along the west coast of the United States.

Tsunami threats in the Atlantic

With respect to tsunami hazard risk to the U.S. East coast, it should be noted that subduction zones are scarce in the Atlantic Ocean. But the Atlantic Ocean is not immune to tsunami. A tsunami following the great 1755 Lisbon earthquake, generated by collision of the African and Eurasian tectonic plates, devastated coasts of Portugal and Morocco, reached the British Isles, and crested as much as 20 feet high in the Caribbean.

In 1929, the magnitude 7.2 Grand Banks earthquake triggered a submarine landslide and tsunami that struck Newfoundland's sparsely settled coast, where it killed 27 people with waves as high as 20 feet. An event like this, involving a submarine landslide, may be the most likely scenario for the Atlantic coast. Scars of past large submarine landslides abound on the continental slope off the U.S. Atlantic coast. As in the 1929 Grand Banks event, some of the slides probably resulted from large earthquakes. If earthquakes are the primary initiator of the observed landslide features, the hazard to the Atlantic coast is limited as large earthquakes rarely occur in the vicinity of the U.S. and Canada Atlantic coast--perhaps once a century, on average (Boston area, 1755; Charleston, 1866; Newfoundland, 1929). Additionally, this type of tsunami would affect a much smaller geographical area than one generated by a subduction zone, and its flooding effect and inundation distance would be limited. Much work is needed, however, to more fully understand the triggering of submarine landslides and the extent of that threat in the Atlantic.

Another tsunami scenario for the Atlantic coast that has been widely publicized is a landslide involving collapse of part of the Cumbre Vieja volcano in the Canary Islands into the sea. While this collapse would be dramatic and might indeed induce a transatlantic tsunami, such a collapse may occur only once every hundred thousand years. Furthermore, unlike the West Coast with the abundant record of past ocean-wide tsunami deposits, no such regionally extensive deposits have been found to date along the Atlantic coast.

Tsunami threats in the Caribbean

The Caribbean is subject to a broad range of geologic processes that have the potential to generate tsunami. Indeed, the Caribbean tectonic plate has almost all of the tsunami-generating sources within a small geographical area. Subduction zone earthquakes of the type that generated the Indian Ocean tsunami are found along the Lesser Antilles and the Hispaniola and Puerto Rico trenches. Other moderately large earthquakes due to more local tectonic activity take place probably once a century, such as in Mona Passage (1918 tsunami) and in the Virgin Islands basin (1867 tsunami). Moderate earthquakes occur that may trigger undersea landslides and thus generate tsunami. An active underwater volcano (Kick'em Jenny near Grenada) where sea floor maps show previous episodes of flank collapse also poses a tsunami hazard. Above-water volcanic activity occurs, wherein the Lesser Antilles periodically generate landslides that enter the sea to cause tsunami. And finally, the possibility exists of tele-tsunami from the African-Eurasian plate boundary, such as the great Lisbon earthquake of 1755 described above.

In 1867, an 18-foot high tsunami wave entered St. Thomas' Charlotte Amalie at the same time that a 27-foot wave entered St. Croix's Christiansted Harbor. Were that to occur again today, the 10-fold increase in population density, the cruise ships, petroleum carriers, harbor infrastructure, hotels and beach goers, nearby power plants, petrochemical complexes, marinas, condominiums, and schools, would all be at risk.

On October 11, 1918, the island of Puerto Rico was struck by a magnitude 7.5 earthquake, centered approximately 15 kilometers off the island's northwestern coast, in the Mona Passage. In addition to causing widespread destruction across Puerto Rico, the quake generated a medium sized tsunami that produced runup as high as 18 feet along the western coast of the island and killed 40 people, in addition to the 76 people killed by the earthquake. More than 1,600 people were reportedly killed along the northern coast of the Dominican Republic in 1946 by a tsunami triggered by a magnitude 8.1 earthquake.

In contrast to the Caribbean, the Gulf of Mexico has low tsunami risk. The region is seismically quiet and protected from tsunami generated in either the Atlantic or the Caribbean by Florida, Cuba, and broad continental shelves. Although there have been hurricane-generated subsea landslides as recently as this fall, there is no evidence that they have generated significant tsunami.

Lessons learned: What the United States can do to better prepare itself and the world

Natural hazard events such as the one that struck Sumatra and the countries around the Indian Ocean on December 26, 2004, are geologically inevitable, but their consequences are not. The tsunami is a potent reminder that while the nations surrounding the Pacific Ocean face the highest tsunami hazard, countries around other ocean basins lacking basic tsunami warning systems and mitigation strategies face considerable risk. Reducing that risk requires a broad, comprehensive system including rapid global earthquake and tsunami detection systems, transmission of warnings in standardized formats to emergency officials who already know which coastal areas are vulnerable through inundation mapping and tsunami hazard assessment, and broadcast capabilities to reach a public already educated in the dangers and how to respond. For tsunami crossing an ocean basin, an adequate system of earthquake sensors, Deep-ocean Assessment and Reporting of Tsunamis (DART) buoys, and tide gauges should allow for timely warnings if the rest of the system is in place. For tsunami generated near the coastline, time is considerably more critical. For tsunami warnings to be effective, they must be generated and transmitted to the affected coastline within a few minutes of detection, local emergency responders must be prepared, the population must be informed, and the entire system must be executed without delay.

The Sumatra earthquake and its devastating effects will encourage us to continue forward on the comprehensive NEHRP approach to earthquake loss reduction. USGS is committed to do so in partnership with FEMA, the National Institute of Standards and Technology, and NSF to translate research into results through such initiatives as ANSS, the George E. Brown, Jr. Network for Earthquake Engineering Simulation, the plan to accelerate the use of new earthquake risk mitigation technologies, and development of improved seismic provisions in building codes.

As part of the President's plan to improve tsunami detection and warning systems, the USGS will:

1. Implement 24 x 7 operations at the National Earthquake Information Center and upgrade hardware and software systems in order to improve the timeliness of alerts for global earthquakes. As part of the upgrade, USGS will fully develop what is now a prototype system to estimate the number of people affected by strong ground shaking after an earthquake using our ShakeMap model and databases of global population. Known as Prompt Assessment of Global Earthquakes for Response (PAGER), this system can provide aid agencies and others with a quick estimate of how significant the casualties might be well in advance of reports from affected areas where communications may be down.

2. Support research to develop more rapid methods for characterizing earthquakes and discriminating likely tsunamigenic sources.

3. Improve the detection response time of the Global Seismographic Network by making data from all stations available in real time via satellite telemetry and improving station up-time through increased maintenance schedules. Improved coverage in the Caribbean region will be achieved through the addition of stations and upgrades of existing stations through international partnerships and cooperation.

4. Further the use of software developed by the California Integrated Seismic Network (a USGS, university and State partnership) to speed USGS-generated earthquake information directly to local emergency managers with a dual use capability to also provide NOAA tsunami warnings.

5. Enhance existing USGS geologic and elevation mapping for coastal areas in the Caribbean. Such mapping is critical to development of improved tsunami hazards assessments for Puerto Rico and the U.S. Virgin Islands.

The USGS will also continue its ongoing efforts to improve tsunami hazard assessment and warnings through geologic investigations into the history of and potential for tsunami occurrence; coastal and marine mapping; modeling tsunami generation, source characterization, and propagation; and development of assessment methods and products such as inundation maps with NOAA, FEMA, and other partners. USGS will also continue strong partnerships with state tsunami and earthquake hazard mitigation groups and contribute to public awareness efforts. An example of the latter is the 2001 publication, USGS Circular 1187, Surviving a Tsunami: Lessons Learned from Chile, Hawaii and Japan, which was prepared in cooperation with the Universidad Austral de Chile, University of Tokyo, University of Washington, Geological Survey of Japan, and the Pacific Tsunami Museum. Continuing investigations of the Indian Ocean tsunami provide a critical opportunity to expand our knowledge of tsunami generation and impacts and to evaluate the research and operational requirements for effective hazard planning, warning, and response systems.

Mr. Chairman, I thank you for this opportunity to appear before the Committee and would be happy to answer any questions now or for the record.